Study of Venus cloud layers by polarimetry using SPICAV/VEx

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1. Context

- Since 1929, polarization has been used to characterize Venus' clouds and hazes refractive index, radius and particle size distribution;
- Most of our knowledge is based on measurements and modeling made by Lyot[4], Hansen and Hovenier[1], Kawabata[2] and Sato[8] with ground and space observation;
- Our goal here is to make new measurements using the polarimetric data provided by the instrument SPICAV-IR on Venus Express, in orbit since 2006.

	Main cloud layer	Hazes
Altitude	50 to 75 km	30 to 90 km
Composition	H_2SO_4–H_2O	H_2SO_4–H_2O
Radius	$r \sim 1$ µm	$r \sim 0.25$ µm

Table: Current knowledge of Venus clouds.

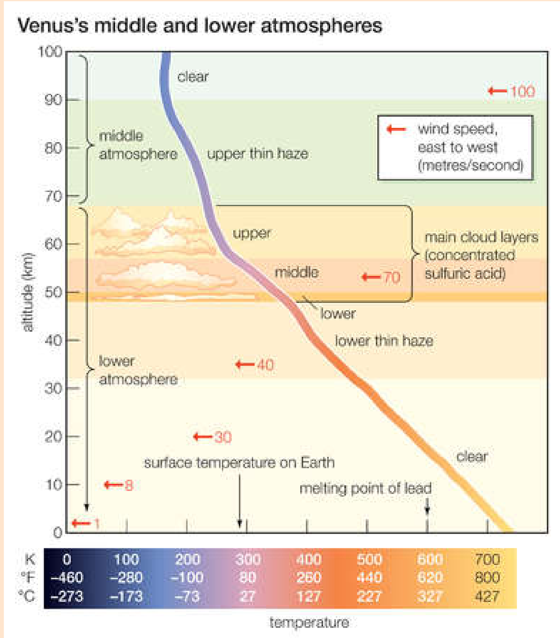

Figure: Structure of Venus clouds

2. SPICAV-IR

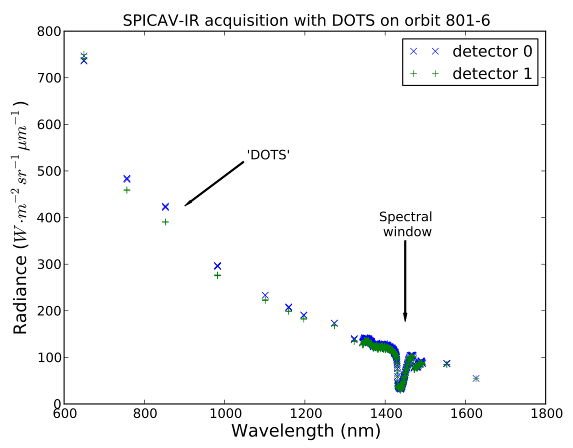

Figure: Example of SPICAV acquisition.

Channel	Coverage
SW	0.65 µm—1.05 µm
LW	1.05 µm—1.7 µm

Table: SPICAV characteristics

SPICAV-IR is a spectrometer on-board the Venus Express spacecraft[3]. Based on an Acousto-Optical Tunable Filter (AOTF), it produces two beams linearly polarized in perpendicular directions.
Measure of the degree of linear polarization:

$$P_\ell = \frac{P_\perp - P_{//}}{P_\perp + P_{//}} = \frac{d_1 - d_0}{d_1 + d_0}$$

Cross-calibration performed by knowing that for any wavelength $\mathbf{P}_\ell = \mathbf{0}$ **at** $0°$ **of phase angle**. Acquisition is made with spectral windows and sets of 3, 5 or 10 points for continuum measurement. We use the latter points to **measure polarization in up to 14 wavelengths[7]**.

3. SPICAV observations

- Observations performed in nadir, spot-tracking mode and with *zig-zags* for SO_2 mapping;
- VEx has a north polar orbit: observations mostly located in northern hemisphere;

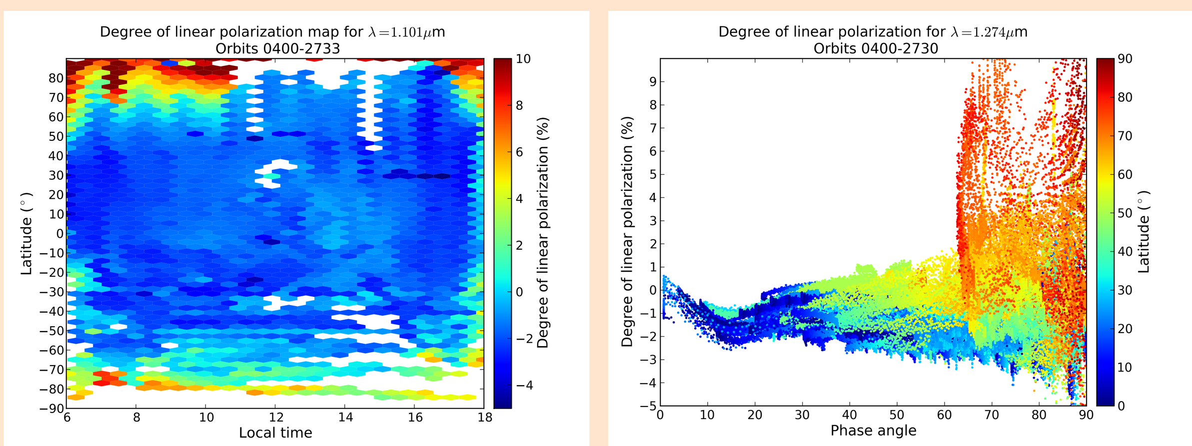

Figure: **Left:** Average maps from SPICAV polarization observations at 1101 nm for all orbits from 2007-05-26 to 2013-10-16. **Right:** Polarization nadir observations at $\lambda = 1.274$ µm for the same period as a function of phase angle and latitude. The glory is visible at $\sim 15°$ of phase angle.

Polarization is quite uniform across the planet with the exception of the high latitudes:
- At low latitudes, the polarization is mostly negative;
- At higher latitudes it becomes positive, reaching values sometimes higher than +10%;
- A phenomenon known as **glory** is visible nearly every time SPICAV-IR observes at low latitudes;
- The glory is **also observed in photometry** by the Venus Monitoring Camera (VMC) onboard Venus Express[5, 6].

4. Cloud model

- The cloud model has a layer of haze above a cloud layer, each homogeneously mixed;
- Polarization retrieved with the doubling-adding method[9];
- Angular position and shape of the glory dependent on the cloud parameters: **the glory is a tool to characterize the cloud layer**;
- Thickening hazes increases the polarization degree near 90° of phase angle: **possible measurement of** τ_h **at higher phase angles.**

	r_{eff}	ν_{eff}	n_r	τ
Haze layer	0.25	0.25	n	τ_h
Cloud layer	r_c	ν_{eff}	n	30

Table: Parameters of the cloud model

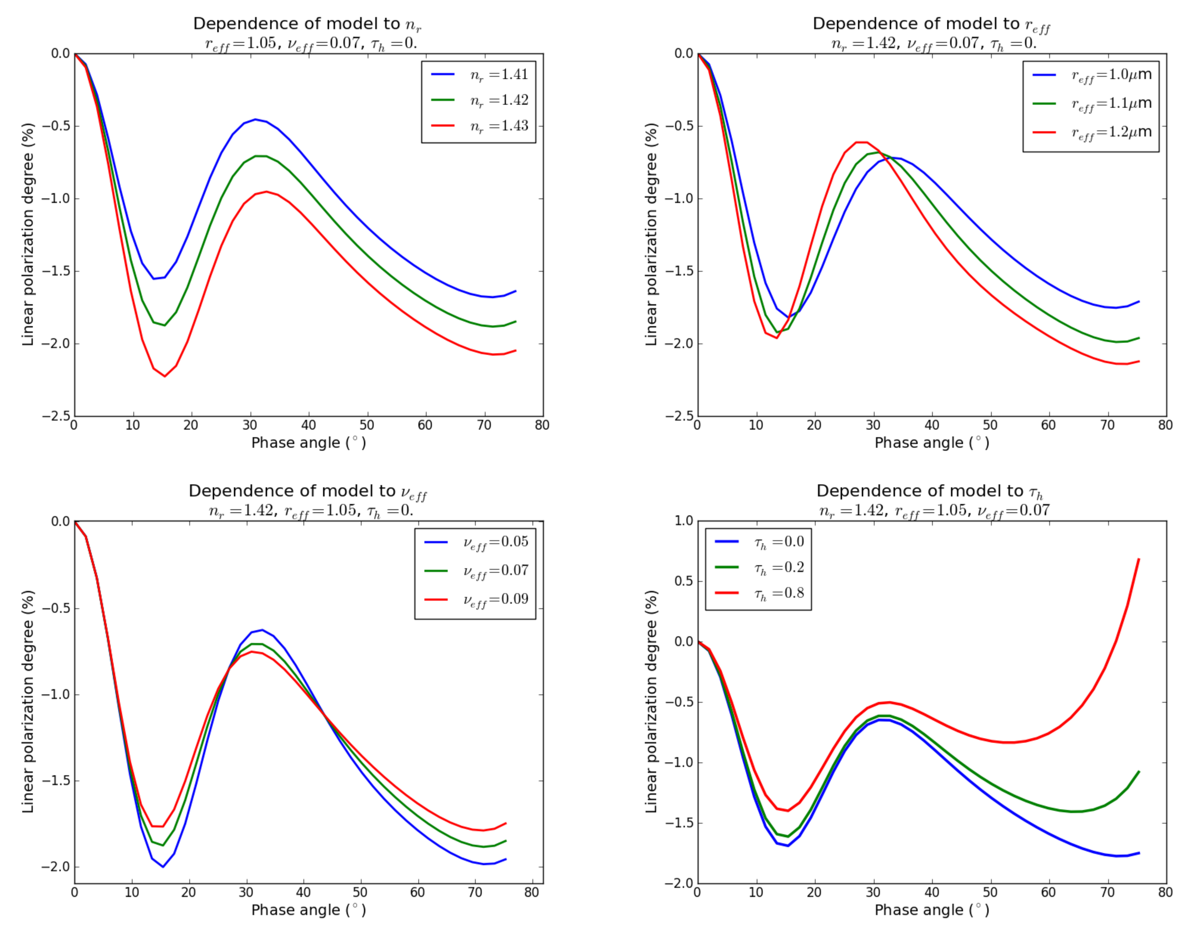

Figure: Illustration of the influence of the cloud parameters n_r, r_{eff}, ν_{eff}, and τ_h on the model.

5. Glory analysis

Cloud parameters n_r, r_{eff}, ν_{eff} retrieved from 10 selected glories using our model at six wavelengths simultaneously (1.101, 1.16, 1.198, 1.274, 1.324 and 1.553 μm).

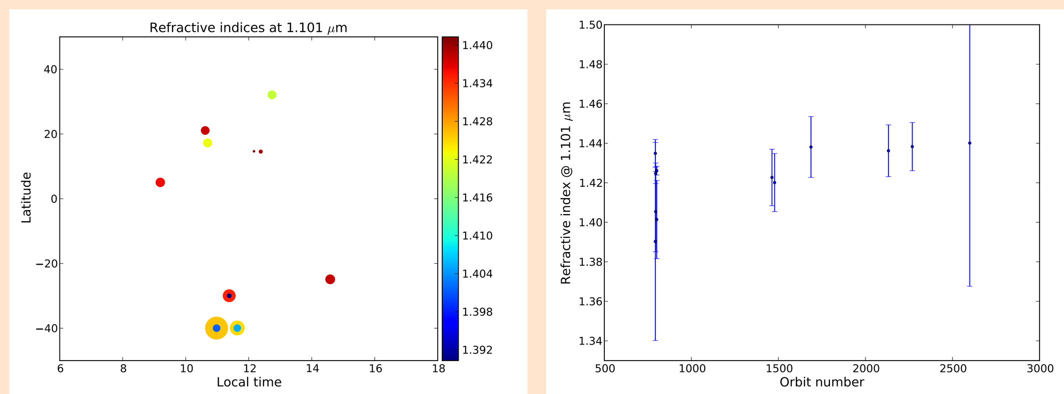

Figure: Retrievals of refractive indices from glory observations as a function of (from left to right) latitude/local time and orbit number. Size of marker is inversely proportional to uncertainty.

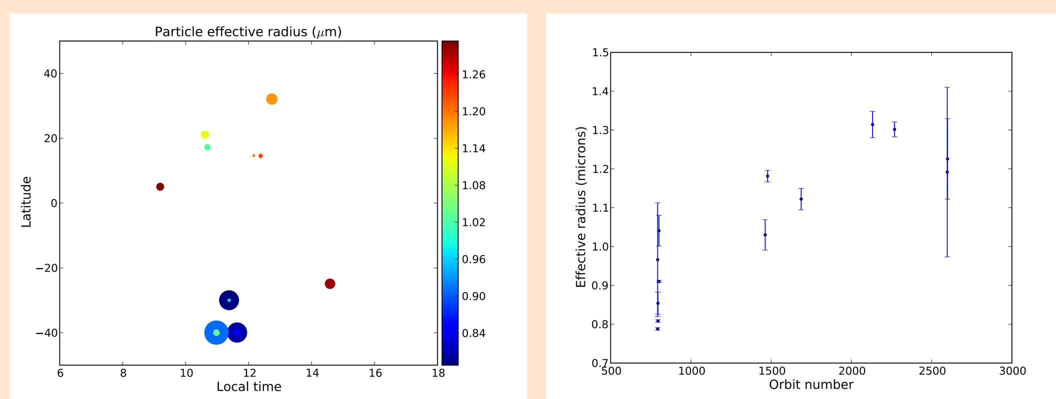

Figure: Retrievals of effective radii from glory observations as a function of (from left to right) latitude/local time and orbit number. Size of marker is inversely proportional to uncertainty.

- Refractive indices of $\mathbf{n_r} \sim \mathbf{1.44}$ at $\lambda = 1.1$µm, **compatible with concentrated** $\mathbf{H_2SO_4}$ **solution**;
- Particle effective radius varying in range $\mathbf{0.8} < \mathbf{r_{eff}} < \mathbf{1.3}$**µm**, ;
- Upper limit on variance of the size distribution: $\nu_{\mathrm{eff}} < 0.15$;
- Small haze column densities required $\mathbf{C_h} < \mathbf{1}$**µm**$^{\mathbf{-2}}$ **at low latitudes**.
- Too few usable glories to make any conclusion regarding latitudinal or local time trends. Possible increase of n_r and r_{eff} with time.

6. Higher latitudes

At higher latitudes, thicker haze is required to match observed polarization.
- A fixed composition of the cloud layer is assumed in order to derive the haze column density. For the cloud $r_{\mathrm{eff}} = 1.05$µm, $\nu_{\mathrm{eff}} = 0.07$ and $n_r = 1.44$ at 1.101 µm.
- The haze effective radius and variance are set to $r_{\mathrm{eff}} = 0.25$ µm and $\nu_{\mathrm{eff}} = 0.25$.
- Fits performed at all latitudes in the northern hemisphere;
- **The properties of the clouds change with latitude, with increasing haze column density with increasing latitude**. This is in agreement with OCPP measurements.
- A small decrease of C_h occurs between equator and 50° of latitude, followed by a sharp increase towards the pole.
- Kawabata[2], observed an increase in the haze column density with increasing latitude (from 0.23 µm^{-2} at low latitudes to 3.1 µm^{-2} at high latitudes). Our values fall within this range.

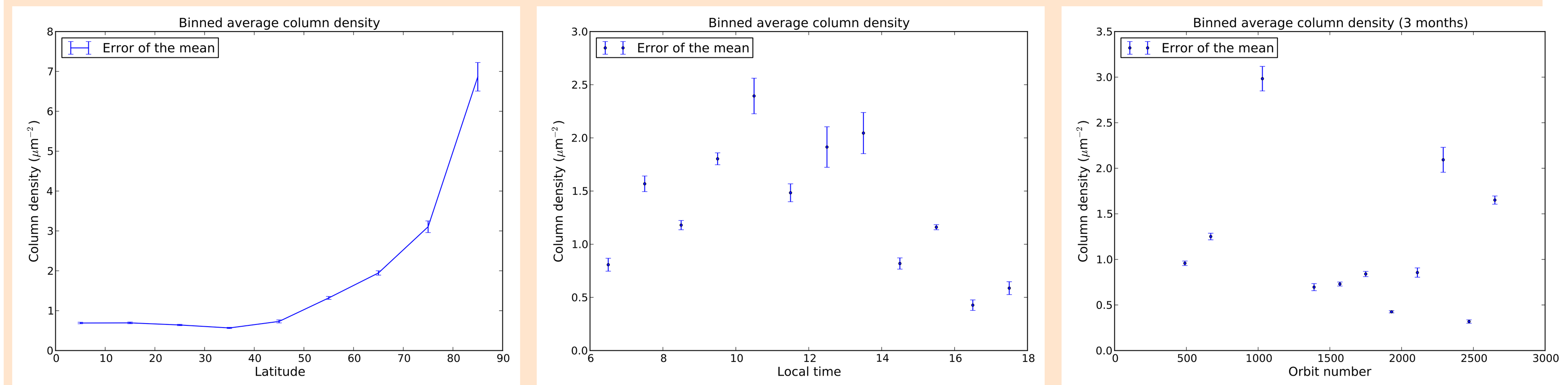

Figure: Binned averaged values of haze column density as a function of (from left to right) latitude, local time and orbit number.

7. Conclusion and perspectives

Conclusion

- SPICAV polarization data is fully exploitable with **a large spatial and temporal coverage**;
- **Consistent with previous observations** : same features and order of magnitude;
- The glory is observed every time at phase angles $\sim 15°$: spherical micrometric particles constitute most of the clouds of Venus;
- Refractives indices retrieved are **compatible with sulfuric acid solution**;
- An **increase of the haze column density** is observed **with increasing latitude**.

Perspectives

- Investigate further the temporal and spatial variability, in particular for the haze column density;
- Possible information on vertical structure of the clouds from polarimetry in the CO_2 absorption band.

For further information on the instrument and/or method, please refer to **Rossi et al. 2014** (in press) [7].

References

[1] J. E. Hansen and L. D. Travis. Light scattering in planetary atmospheres. *Space Sci. Rev.*, 16:527–610, Oct. 1974.

[2] K. Kawabata, D. Coffeen, J. Hansen, W. Lane, M. Sato, and L. Travis. Cloud and haze properties from Pioneer Venus polarimetry. *J. Geophys. Res.*, 85:8129–8140, dec 1980.

[3] O. Korablev, A. Fedorova, J.-L. Bertaux, A. Stepanov, A. Kiselev, Y. Kalinnikov, A. Titov, F. Montmessin, J. Dubois, E. Villard, V. Sarago, D. Belyaev, A. Reberac, and E. Neefs. SPICAV IR acousto-optic spectrometer experiment on Venus Express. *Planet. Space Sci.*, 65:38–57, may 2012.

[4] B. Lyot. *Recherches sur la polarisation de la lumière des planètes et de quelques substances terrestres*. PhD thesis, Université de Paris, 1929.

[5] W. Markiewicz, E. Petrova, O. Shalygina, M. Almeida, D. Titov, S. Limaye, N. Ignatiev, T. Roatsch, and K. Matz. Glory on venus cloud tops and the unknown uv absorber. *Icarus*, 234:200–203, 2014.

[6] E. V. Petrova, O. S. Shalygina, and W. J. Markiewicz. The vmc/vex photometry at small phase angles: Glory and the physical properties of particles in the upper cloud layer of venus. *Planetary and Space Science*, (0):–, 2014.

[7] L. Rossi, E. Marcq, F. Montmessin, A. Fedorova, D. Stam, J.-L. Bertaux, and O. Korablev. Preliminary study of venus cloud layers with polarimetric data from spicav/vex. *Planetary and Space Science*, (0):–, 2014.

[8] M. Sato, L. Travis, and K. Kawabata. Photopolarimetry Analysis of the Venus Atmosphere in Polar Regions. *Icarus*, 124:569–585, dec 1996.

[9] D. M. Stam, J. F. De Haan, J. W. Hovenier, and P. Stammes. Degree of linear polarization of light emerging from the cloudless atmosphere in the oxygen A band. *J. Geophys. Res.*, 104:16843–16858, 1999.

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